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The role of science education in a changing world

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The Role of Science Education in a Changing World

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The Role of Science Education in a Changing world

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SCIENCE EDUCATION IN A CHANGING WORLD

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SCIENCE EDUCATION IN A CHANGING WORLD

Introduction

Significant and rapid development in science, engineering, and technology such as a production and proliferation of mobile and electronic devices, robotics, digital communication and information systems have enabled instant flow, and exchange of various forms of data, work, and capital. These developments and activities have forever transformed the nature and organization of life, including human, non-human, and more-than-human life. Despite all the advancements, in the awaking of the second millennium the world finds itself facing a series of globally interconnected and locally specific challenges: climate change, the quality and security of food, water and air pollution, political instability, refugee crisis, poverty, migration, racisms, sexism, gender bias, and various other forms of sociopolitical and economic inequalities and oppressions. Many of these challenges are arguably intertwined with, if not the direct result of, scientific and technological activities, globalization processes, and associated neoliberal economies, values, ethics, and behaviors. As Faber and McCarthy (2003) cogently argue, “As a result, the issues of sustainable development and social/environmental justice have surfaced together as in no other period in world history...[both] a part of the same historical process” (p. 40). Science education, which cuts across the persistent divide of natural sciences and social science, is potentially uniquely positioned to support new generations’ understanding and engagement and address the social, economic and environmental dimensions of these global challenges. Scientific knowledge is vital for effective action, however, a new vision of contemporary societies that are socially inclusive, just and equitable, ought to be at the heart of the account of

our efforts in averting a continuous, growing global crisis. Hence, addressing goals related to diversity and equity in science education becomes of crucial importance in light of the big picture of a rapidly changing world.

Concurrently, different reform efforts and related policy documents have been published in various parts of the world (e.g., New Generation Science Standards in the U.S. context, Responsible Science and Innovation in Europe). The question is: how aligned are these recommendations for reform in science education with current sociopolitical contexts? An examination of these recommendations shows that there exists a discrepancy between contemporary global challenges and reform efforts, which focus on goals related to economical competition instead of goals related to students’ well-being and social justice.

One such example can be found in a report published by the European Federation of National Academies of Sciences and Humanities in 2012 entitled “A renewal of science education in Europe”. The report places emphasis on the importance of ‘inquiry-based education’ as a means for supporting students’ interest in science and advancing their scientific literacy. However, these recommendations proved to be disconnected from the nature of the various and diverse sociopolitical contexts of Europe, during times when a continuing economical turbulence has been resulting into new social realities (youth unemployment) population demographics (refugees, migrants) and inequalities.

Another example comes from a more recently published report by the European Commission called “Science Education for Responsible Citizenship” (EC, 2015), which offers a 21st century vision for science for society within the broader European agenda. The report places emphasis on the process of aligning research and innovation to the values, needs and expectations of society, referred to as “responsible research and innovation”. Four of the six main objectives of the report are summarized into the following, as an example:

- Science education should be an essential component of a learning continuum for all, from pre-school to active engaged citizenship.
- Science education should focus on competences with an emphasis on learning through science and linking science with other subjects and disciplines.
- The quality of teaching, from induction through pre-service preparation and inservice professional development, should be enhanced to improve the depth and quality of learning outcomes.
- Collaboration between formal, non-formal and informal educational providers, enterprise and civil society should be enhanced.

This document is framed around the challenge of increasing the number of students interested in scientific careers because Europe faces a shortfall of scientists. Unlike previously published reports, this one offers a more comprehensive vision of reform in science education. However, the reform recommendations fall short in two distinct ways: (a) they are atheoretical as they are not rooted in any learning theories, paradigms, or frameworks; and, (b) they do not reflect how global challenges have shaped this vision for science for society and therefore lack attention to the need for more inclusive, equitable, and just societies. The word ‘theory’ is not used once in the entire 88-pages long document with no

references made to research on science teaching and learning. Moreover, no attention to issues related to diversity, in terms of ethnicity, language, gender, religion, is paid. In addition, a discussion of the role of the discourse of science or how students talk and write science is missing as well as the role of the local context and the involvement of families in children’s education. Lastly, goals related to reducing inequality, promoting social change and social justice are completely absent.

These issues, among others related to scientific practices as well as teacher education, were discussed in an international week-long workshop with title “Science Education for a Changing World”, funded by the Lorentz Center in the Netherlands, which brought together a group of 25 researchers from 13 different countries (Canada, Chile, China, Cyprus, Korea, Lebanon, Luxembourg, Netherlands, Spain, Sweden, Turkey, UK, and USA). The driving question of the workshop was: *How can scientific knowledge be utilized through education to address global challenges?* Four working groups were formed around four main research areas:

- The role of science education and teacher preparation in society
- Nature of science and social justice
- Identity, equity, and gender
- Scientific practices and argumentation

Each of these groups worked to develop a set of recommendations for reform in science education, in light of the current geosociopolitical context and with the purpose of addressing global challenges. In what follows, we share only a snapshot of the recommendations put forward by the third group who explored issues related to equity, identity and gender.

DIVERSITY AND EQUITY

Achieving equitable learning opportunities and outcomes for, and among, all students is one of the most pressing challenges facing science education. Conceptions of equity is one of the most ubiquitous, and yet undertheorized concepts in science education (Dimick, 2012). Most often, equity in science education is associated with notions of distribution, access, opportunity, empowerment, and broadening participation. Teachers and teacher educators committed to social justice issues examine inequities in structural, cultural, and curricular organization of schools, namely racist, classist, sexist, and gendered discourses and practices, as one of the main reproductive systems of social and economic disparities in the society, and work to dismantle them by “empowering” students socially, politically, and academically. Elsewhere, Kayumova, McGuire and Cardello (2018), posit that equity and justice efforts limited to notions of broadening participation, achievement, and access, might be insufficient to transform systems of domination and to understand complexities inherent in globally complex and locally specific sociopolitical, economic, spatial, and environmental disparities. If anything, Kayumova, McGuire and Cardello argue, that empowerment must be about supporting and legitimizing children’s, families’, and diverse communities’ existing knowledge bases, skills and power to contribute to decision making and their rights to respond, response-ability, to the issues and topics discussed about, and on behalf of them and their children.

Kayumova and Tippins (2018) underline the importance of expanding the notions of equity and justice by examining the dominant epistemological and ontological assumptions in the cultural and curricular organization of science education (e.g., how nature-culture relations are taken up in the current science standards), research methods and methodologies employed and understanding and framing of the justice issues, which left unexamined, might risk perpetuating the very inequities that equity-oriented scholarship seeks to transform. For example, much of the research that is considered to be an equity oriented might become complicit, if not inadvertently participating, in perpetuation of deficit discourses about student populations (e.g., girls, cultural and linguistic minorities, Black and Brown children) and communities when they do not question and examine taken for granted assumptions and methodologies in studying these populations. In the context of the U.S., Kayumova, Karsli, Allexsaht-Snider and Buxton (2015) have documented that language identities and repertoires of emergent bilingual and multilingual children become a part of myriad axes of marginalization intertwined with their social positioning (e.g. race, class, and gender) given that science classrooms operate on certain dominant norms of English language usage. This is also true for many European countries, which are seeing a new surge of immigrant and refugee populations (UNHCR, 2016).

Consequently, dominant English language based performativities of students operate as yet another academic normativity along which notions of cognition, intelligence, capability, and other forms of cognitive assumptions and deficit discourses become conceived and against which students from culturally and linguistically diverse communities and their differential learning performances are judged (Kayumova & Ji, 2018).

Science education research in mainstream channels has been dominated by established binary-categories (e.g., boys vs. girls, native vs. immigrants) and compare/contrast models that both establish artificial commonalities and use differences as a way to construct, justify and reproduce systems of power in relation to science education. A paradigm shift is needed where researchers adopt multiple sociocultural and diverse theoretical lenses, rooted in sociocultural, critical, and radical approaches, epistemologies and ontologies (i.e., critical race theory, radical feminism, anticolonial theory), and/or consider bringing theoretical perspectives into conversation with one another in novel ways that when examining learners participation in, and relationship to science, as an alternative prism that allows us to look into students' lives and to address goals related to equity, diversity, and power differentials. These goals are directly linked to the following key questions, which we argue ought to be addressed by contemporary research in science education:

- How do we address science teaching, learning and research challenges in increasingly diverse contexts that are shaped by migration, multiculturalism and resulted diversity?
- What approaches can we use so that the social, political, historical and educative aspects are considered in our research? How do we capture the complexities of these issues?
- What new questions and approaches can we use so that we do (a) not reproduce the inequities in science teaching and learning contexts; and, (b) advance equity in science teaching and learning contexts? Further, how are we (re)defining equity in science?
- What are the ways that power is reproduced in science education research spaces? What could we do to elucidate, unpack and disrupt these power dynamics?

One way of understanding the different approaches to science education that centers diversity is through “anti-oppressive education”. (Kumashiro, 2000) has categorised four kinds of anti-oppressive education which focuses on the following: (a) education for the other; (b) education about the other; (c) education that is critical of privileging and othering; and, (d) education that changes students and society. As science education researchers and science teachers, we need to be knowledgeable about the plurality of such approaches and knowing when to use what and the affordances and constraints of the different approaches. We also emphasize the need to identify and employ notions of science as socially constructed, in research and in teaching, in ways that honor the social, cultural, and historical contexts that have influenced and that continue to contribute to the nature of science.

The science education community also needs to consider the diverse ways of knowing, being, describing the natural world among diverse socio-cultural

groups, which might be different from the dominant ways in which hegemonic science education understands and explains it. For instance, aboriginal and indigenous communities' ways of relating to the nature and culture defy traditional nature-culture binaries by which classical science operates. Utilizing indigenous and aboriginal theories in understanding diverse students and their family's relations to dominant science perspectives, can help science education to be more inclusive and make bridges (include?) to the cultures and groups traditionally left out of hegemonic science. Moreover, it will also help us to overcome a dichotomy of what appears to be a Western and indigenous knowledge systems, and support the equity efforts.

Specific constructs feature centrally in addressing these goals and essentially in adopting a science in society instead of a science for society paradigm.

Diversity

Diversity refers to the inclusion of different types of people. Science education often emphasizes ethnicity/race, gender and socioeconomic status/social class as important social constructs through which one can examine the issues of diversity. However, we must also consider the various ranges and constructs of diversity that also influence science teaching, learning and research such as dis/ability, linguistic, sexuality, gender identity, political, religious, geographical, age [etc.]. Our approaches to diversity need to take into consideration the potentialities of this also about using different theoretical lenses in order better to elucidate the ways in which inclusion and exclusion, of peoples and knowledges, happens within science education. For example, using critical whiteness studies to unpack power structures embedded in science education and other "norms" that are taken for granted in science-related contexts.

Equity

In science education, equity is often taken to mean broadening participation, achievement, and/or access. A reconceptualisation of equity is needed, that takes into account how science education is intrinsically linked to power, culture, epistemology, and identity. Doing well on achievement measures does not necessarily, by itself, imply equity. Similarly, broadening participation and access are not enough to transform systems of domination. To this end, we underline the importance of examining issues of power and equity within the structural, cultural, and curricular organization of science education, teaching and learning. We also propose considering and recognizing how as researchers our practices of knowledge production and dissemination are consequential to equity efforts, and if not afforded internal scrutiny and continuous reflexivity, might become complicit in the reproduction of the very inequities we seek to transform.

Intersectionality

Intersectionality is used to highlight the inseparability of categories of social differences such as race, gender, sexuality, ethnicity, and nationality (Crenshaw, 1989). Intersectionality calls for an emphasis on the systemic power dynamics that arise as multiple dimensions of social interactions across individual, institutional, cultural and societal spheres of influence and is used to address inequality and discrimination in relation to engagement with science. As a term, coined by Kimberlé Crenshaw in 1989 to counter the disembodiment of Black women from law, intersectionality captured the inadequacy of legal frameworks to address inequality and discrimination resulting from the ways race and gender traversed to shape the employment experiences of Black women. Intersectionality scholarship can assist in revealing key concerns; namely, the existence of a multiplicity of power-relations, of the interlacing of social dynamic categorizations based on gender, race, and ethnicity and other social constructs.

Identity

Using ‘subjectivity’ or other theoretical constructs might be better to avoid falling in the everyday meaning of the word identity, and emphasizing understanding identity construction through social participation and lived experience (Avraamidou 2014; 2018). We can also consider identity as it relates to the ways in which students position themselves with relation to others: “Who one is and who one desires to be at any given moment is always under negotiation and is contingent upon the resources one has access to and the social, cultural, and historical context in which one seeks to author oneself against the expectations of others” (Holland, Lachiotte, Skinner, & Cain, 2001 p. 120). For instance, students’ diverse ways of being and knowing are structured by their social and cultural experiences of race, class, gender, and sexuality. These social constructs play crucial role by which students are recognized or misrecognized as they perform dominant science practices. Identity can also be used as a lens to understanding science teachers’ learning and development.

Creativity

Creativity is becoming a more popular construct in science especially in association with notions of innovation and scientific entrepreneurialism. However, narrow conceptions of creativity in science only serve to reproduce the inequities and hegemony that currently dominates science teaching, learning and research. Adams (this volume) calls for an expanded view of creativity that both challenges existing scientific epistemologies and centers addressing global challenges from a critical and socially just perspective. In science there is a need to engage in, what Sylvia Wynter (2003) calls “epistemic disobedience” in order to “imagin[e] alternative choices and futures,” especially for the most vulnerable people and places (susceptible to climate change, food insecurity, economic and/or political instability, etc.).

By presenting a notion of scientific creativity that centers wellness, equity and social justice and emphasizes the creation of new knowledge, products and artifacts towards transforming the world for the greater good, we would have a STEM teaching, learning and research framework that would promote the collective well-being of the planet.

The adoption of such theoretical constructs calls for a re-examination of the methodological approaches that we use to respond to research questions related to equity, diversity, and inclusion. Below, we offer a brief list of such methods, which we use in our own research practices, following with examples of current projects:

- Use of life history and narrative approaches that recognize the contextual nature and continuity of experiences with science across time and contexts (Avraamidou, 2018)
- Methodological approaches that value the co-creation of knowledge through centering learners’ lived experiences and voices, such as participatory action research and dialogic data collection methods (Strong, 2016)
- Use of methodological approaches that seek to disrupt boundaries (for example the use of plurilingualism as an analytical lens to view communicative resources versus a lens of multi-or bilingualism)
- Use of methodological approaches that forefront research-to-practice so that we are learning about diversity and equity in learning environments as we also create learning environments that value diversity and learning
- Use of methods and methodological approaches that will allow us to position our participants as critical research partners (Kayumova, 2018), by blurring the hierarchical boundaries of researcher-researched.

EXAMPLES OF PROJECTS

PROJECT 1

Beyond Gender - Intersectional Identities as a Lens to Examining Women's (Non-) Participation in Science

Lucy Avraamidou

Framed within the construct of science identity, this project presents a qualitative multiple-case study on the under-representation of women in scientific careers. Grounded within a combined theoretical framework of intersectionality, identity, and narrative, the project aims at examining the lived experiences and educational pathways of eight purposefully selected female scientists who work in various STEM-related fields in the Netherlands. In exploring the participants' life histories, I pay special attention to the obstacles and barriers they faced throughout their studies and careers. The design of the study is situated within literature that has used gender as a theoretical construct to examine the under-representation of women in science, which, however, as I argue, provides a limited and single-sided understanding of why women are underrepresented in the sciences. The analysis of the participants' life-histories in relation to science are expected to

produce knowledge that that can be used as input for: (a) carrying out large-scale empirical research; (b) rethinking institutional change through intersectionality; and, (c) designing inclusive and equitable workplaces. From a theoretical perspective, the goal of this project is to put an argument forward about the use of relational identities and intersectionality as a lens to examining women's career trajectories in STEM. Such a lens provides a more comprehensive, diverse, and multidimensional frame while it pays attention to the ways in which culture, religion, ethnic status, class, family status, sexuality, and race, intersect with science identity. This deeper and comprehensive understanding of how different identities, social markers, and life-experiences might influence women's science career trajectories allows us to shift the focus away from a deficit model where gender alone is considered.

PROJECT 2

ILETES-Informal Learning Environments and Teacher Education for STEM

Jennifer D. Adams

This research examines the relationship between teacher education and learning to teach vis-a-vis the racialized and politicized structures of urban schools. As a collective of researchers we specifically address questions around the relationship between teachers' (ongoing) learning and understandings, (re)definitions and enactments of informal science education in formal classrooms and the reiterative relationship between practice and identities. Emerging from this project are understandings of Black and Latino teachers, as racialized bodies, in science classrooms and the ways that they either take up, resist and/or transform discourses around students of African and Latinx descent and STEM. Using a

framework of racial storylines (Nasir, Snyder, Shaw & Miraya Ross, 2012) and seeking events that charge identity (Saldanha, 2006), this project learns how messages about race present in schools and how these discourses influenced teaching enactments and identity. Within the different schooling contexts teachers recreated meanings of informal science education and enacted teaching in relation to how they viewed themselves vis-à-vis their students. Their goals for creating STEM learning experiences were shaped and enacted around STEM futures that they imagined for their students and to counter the prevailing deficit discourses around students of color and STEM.

PROJECT 3

*Power, knowledge and identity in science and technology classrooms:
Teachers' enactments of disciplinary discourses as establishing inclusion and exclusion.*

*Anna Danielsson, Maria Berge, Malena Lidar,
Åke Ingerman, Leif Östman and Heather Mendick*

The aim of the project is to explore how knowledge and power are mutually constituted in meaning-making processes in physics and technology classrooms, in relation to the teachers' enactment of a disciplinary discourse. By analysing the interrelationship of knowledge and power, the project seeks to contribute to the knowledge about processes of inclusion and exclusion in physics and technology. The empirical data consists of video-recordings of physics and technology lessons in five different

schools (lower and upper secondary school) and interviews with upper secondary school students. The project is multi-theoretical; the selected publication makes use of a combination of pragmatism and a Foucauldian power perspective, other sub-studies make use of positioning theory or a social semiotic perspective. While the project is mostly focused on the co-constitution of power and knowledge in classroom interactions, there is also a strand exploring students' identity constitution.

PROJECT 4

Analyzing the nexus between advantaged social positioning and science identity development among ethno-linguistically diverse learners.

Shakhnoza Kayumova

The United States has a large population of children from diverse ethnic-racial and linguistic backgrounds. Over 5.4 million of these students are identified as English learners (ELs), with 4.4 million being Spanish-speaking (U.S. Census Bureau, 2012). Currently, the increasing EL student population (NCES, 2015); growing demands for science-, technology-, engineering-, and mathematics- related (STEM) jobs; mounting disparities in ELs' science achievement outcomes, and consequently their substantial underrepresentation in the STEM workforce, constitute

intersecting sources of inequality (Landivar, 2013). The aim of this longitudinal mixed-method study is to analyze how ethno-linguistically diverse learners language identities affect their science identity development using positioning theory as a primary lens. Filling an important gap in the literature, the study brings new empirical evidence related to the intersection of language-based perceptions and science identity development. The project is supported by National Science Foundation Early Career Grant.

INSTEAD OF A CONCLUSION

Collectively, the examples of these projects are grounded in the assumption that in order to make meaningful and transformative changes in science education we need to consider the characteristics of an era of globalization. Such characteristics are the diverse culture and racial origins of students, and language barriers caused by dramatic social changes happening in the world, such as border crossing and migration. These social changes call for a re-visioning of science education that addresses equity and social justice, and which involves a conceptualization of science that goes beyond binary oppositions, beyond borders and boundaries, given that borders are limiting and considering that the boundaries of science are constantly shifting. In doing so, we ought to acknowledge that learning environments are nowadays hybrid and multi-contextual, and learning experiences are complex and multi-dimensional. As researchers interested in issues related to social justice and social justice, we problematize various aspects of science education and we propose new ways of conceptualizing science education shaped at

the intersection of personal, local and global realities. At the heart of the account of this proposition is an examination of the role of science education in addressing global challenges, in the context of current sociopolitical contexts as we question the taken-for-granted spaces, boundaries of science, and traditional discourses.

As our concluding remark, we would like to leave our readers with a quote from a feminist scientist Karen Barad: “Justice, which entails acknowledgment, recognition, and loving attention, is not a state that can be achieved once and for all” (p. X). Any prescriptive account of justice can be essentialized and reproduce the very injustices. As Barad (2007) rightly argues:

There is only the ongoing practice of being open and alive to each meeting, each intra-action, so that we might use our ability to respond, our responsibility, to help awaken, to breathe life into ever new possibilities for living justly. The world and its possibilities for becoming are remade in each meeting (p. X).

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SCIENTIFIC PRACTICES FOR SCIENCE EDUCATION IN A CHANGING WORLD

Introduction

Research and reform documents in science education across the world have been calling for a shift in the emphasis from the products to the processes of science, to make science accessible to students and help them understand its epistemic foundation (Achieve, 2013; Eurydice, 2011; EU Commission, 2015). Scientific practices, part of the process of science, are the cognitive and discursive activities that are targeted in science education to develop epistemic understanding and appreciation of the nature of science.

Scientific practices are those processes underlying scientific inquiry and have been viewed as central in science activity. As such, the term scientific practices refer to the over-lapping practices of modelling, argumentation and inquiry (Osborne 2011). A more operational definition of scientific practices refer to eight processes that take place during scientific activity, which include: asking questions, developing and using models, engaging in arguments, constructing and communicating explanations (NAP, 2011).

Although the teaching of scientific practices is at present being advocated by science education research and included in many curriculums worldwide, there is need for a re-conceptualization of its meaning and implications in the context of 'a changing world'. In the light of the identified global challenges on diversity, economic pressure, global change, and inequality, we propose a framework of scientific practices linked to integrated STEM (inter-disciplinary, multidisciplinary) activities in science, technology, engineering and mathematics that allows students' to address, decide and take action regarding these complex problems in a value-driven, scientific-knowledgeable and empowered manner.

Facing a diverse student community with different cultural and linguistic backgrounds students' engagement in scientific practices will serve as a vehicle for students' language and cultural development. A reconceptualization of scientific practices aims at contributing to citizens' responsibility in a changing world emphasizing well-being for people and communities and a sustainable world – both in local, regional and global contexts.

KEY CHALLENGES

Considering the reconceptualization of science education the following challenges are identified as relevant:

Challenge 1

Leverage the current emphasis on STEM education to better align with epistemic discourse and practices in science and engineering, in order to empower youth to be responsible participants in a changing world.

Challenge 2

To address changes in cultural and linguistic diversity using scientific discourse and scientific practices in ways that embrace a more inclusive vision of identity (language, gender, culture, emotions ...)

Challenge 3

Development of STEM teaching practices balancing between disciplinary-specific pedagogical knowledge, general pedagogical knowledge and disciplinary knowledge.

THEORETICAL OVERVIEW

What are scientific practices and why we think they should be the focus on Science Education in a changing world?

Scientific practices refers to teaching and learning science as the participation in the ways of thinking, doing, communicating and valuing of school science. As such, it encompasses the overarching practices of inquiring, modeling and/or constructing explanations and argumentation (based on Osborne 2014, see figure 1). This framework relates scientific and engineering practices with mathematical and computational thinking and is, as such, representing STEM practices.

Scientific & Engineering Practices

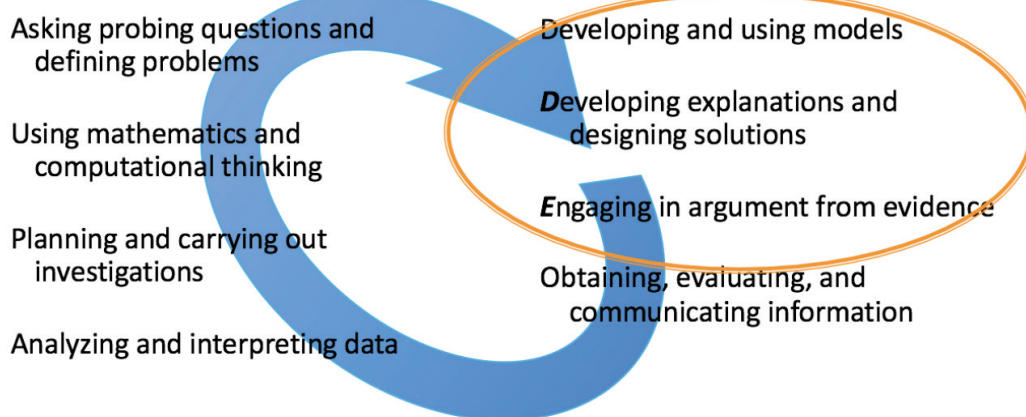


Figure 1: Science and engineering practices (from Osborne, 2014)

What is STEM/STEAM and why leveraging the current emphasis on it to empower youth to be responsible participants in a changing world?

Global challenges are complex, wicked problems requiring multidisciplinary and interdisciplinary approaches. In many teaching practices students learn monodisciplinary knowledge and skills, isolated from their daily lives and from future professions and citizenship (EU Commission, 2015). A STEM framework develops multi- and interdisciplinary thinking in meaningful contexts. STEM may be defined as: “an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems” (Moore et al, 2014, p. 38). However, in the context of a changing world STEM might be defined broader including economy and literacy.

Driven by the techno-scientific vocational crisis, the STEM/STEAM agenda has been taking a lot of notice, seducing both educational and non-educational agents alike. A great number of STEM/STEAM activities, curriculums and programmes are being promoted, colonising the science education innovation, CPD and research scenario. However, it is quite often the case that the activities, CPD courses and curriculum materials of these STEM/STEAM actions and programmes are not of enough quality. One important problem is that they give importance

mostly to transdisciplinary competences (XXI century skills such as critical thinking and communication) rather than to specific STEM competences. As such, they use STEM disciplines more as a knowledge-base than as a practice, bringing us back to the product orientation of the teaching of Science above mentioned. Doing so, they neglect the existing body of research in Science Education regarding the need to participate in the activities that characterise each of the STEM disciplines, which are interestingly different.

A view of STEM from the scientific (and both the engineering and mathematics') framework would allow students to become involved in the different activities and practices of STEM. By doing so, students would learn much more than STEM concepts and ideas: they would learn how to use these STEM ideas and also practices to solve problems creatively and with others, using technology when required. If the value dimension is explicitly added to this picture, the STEM ideas and practices are used with values for the well-being of communities and the environment. Doing so, students could become empowered to address, decide and take action in each of the complex problems they could be addressing, acting as responsible participants in a changing world.

CHALLENGES AND RECOMMENDATIONS

CHALLENGE 1

Leverage the current emphasis on STEM education to better alignment with epistemic discourse and practices in science and engineering, in order to empower youth to be responsible participants in a changing world

Recommendations for Research

1.1 Active participation of Science Education research in the framing of STEAM education in a way that is aligned with the scientific literacy goals we have agreed upon within our community as the main goals of science education with an emphasis on promoting responsible citizenship.

1.2 Understand the context-based nature of STEAM education, the need for local adaptation of STEM practices and experiences aimed at creating responsible citizenship (aims, approaches, effects).

Recommendation for Practice

1.3 Explicit attention to re-envision STEAM activities to reflect scientific practices and discourse (epistemic alignment).

Recommendation for Policymakers

1.4 Support policymakers to understand the wide variation in operationalizing STEAM education and the need to be more thoughtful in conveying STEAM education initiatives and careers opportunities, integrating them into national curriculum documents and standards.

CHALLENGE 2

To address changes in cultural and linguistic diversity using scientific discourse and practices in ways that embrace a more inclusive vision of identity (language, gender, culture, emotions ...)

Recommendation for Research

2.1 Identify and use theoretical and methodological frameworks from other fields (e.g., intersectionality, social network theory) that can inform science education research that addresses challenges of cultural and linguistic diversity, gender and emotion.

2.2 Identify effective learning environments that bridge formal and informal settings in a way that embraces a more inclusive vision of identity (role of communities and different vision of parental involvement in the learning process)

2.3 Conduct focused studies on the role that engaging in scientific practices and discourse plays in learning language.

Recommendation for Practice

2.4 Integrate opportunities for teachers and preservice teachers to work with diverse students and their families in school and out-of-school settings that highlight cultural and linguistic diversity as assets for science learning.

2.5 Create professional learning experiences that integrate scientific practices with language learning theory, pedagogical practices and use of emotions/ self-regulation/ metacognition.

Recommendation for Policymakers

2.6 More funding schemes for science education research that uses inclusive opportunities in science learning to address the holistic needs of all learners

CHALLENGE 3

Development of STEAM teaching practices balancing between disciplinary-specific pedagogical knowledge, general pedagogical knowledge and disciplinary knowledge

Recommendation for Research

3.1 Facilitate the use of new methodologies and research designs that emphasise the design and co-creation of teaching learning sequences.

3.2 Promote research–practice connections that collaboratively engage teachers and researchers in the co-design, study, and assessment of innovative approaches to STEM education.

Recommendation for Practice

3.3 Work with teachers on what STEM education in diverse and equitable science classrooms using approaches such as culturally relevant pedagogies.

3.4 Develop a research-based framework for teacher learning that integrates content and pedagogy (e.g., content courses that model effective pedagogy and methods courses that draw on rich content).

3.5 Develop “images of the possible” of STEM education aligned with epistemic practices to incorporate into teacher education (video analysis, lesson studies, ...).

3.6 Prepare teachers to critically select, adapt, implement and analyze STEM Ed materials and programs.

Recommendation for Policymakers

3.7 Give importance to the on-going professional development of science teachers to address the cultural, linguistic, equity and sustainability issues they have to face using scientific practices as a privileged tool to deal with them.

3.8 Abandon the emphasis in accountability and give more importance to alternative and empowering ways of identifying impact

EXAMPLES OF PROJECTS

A RICH CONTEXT FOR SENSE-MAKING

Carla Zembal-Saul

The second grade teacher, Ms. Windmere, leads a whole class discussion aimed at identifying patterns in evidence that students have been collecting about the relationship between introducing heat energy into a system and melting objects. In the days leading up to this discussion, children worked in small groups to make predictions, record observations, and share initial explanations for the melting of object (e.g., crayon, chocolate, butter, ice). Ms. Windmere sat with small groups, assisted children with safety precautions, asked productive questions, and modeled writing in a science notebook using a small whiteboard. After the melting investigation, the teacher removed the aluminum pans items from the burner and covered each with a box. Student were asked to predict what would happen to the items when they checked them the next day.

The resulting whole class discussion is interesting for several reasons. First, the teacher had students share their results for a purpose – to look for patterns associated with adding heat energy to the system. The way in which Ms. Windmere talked about adding and removing the source of heat demonstrates her knowledge of the underlying concepts and established a productive way for students to think about the system in terms of cause and effect. Second, the teacher’s communicative approach was not one of seeking “right answers” (i.e., Initiation – Response – Evaluation). Ms. Windmere was clearly aware of the pattern from the data, and reframed questions in support of making that pattern visible to students.

Her use of a driving question and KLEWS chart suggests she was using a Claims–Evidence–Reasoning approach to inform her instructional moves. Finally, Ms. Windmere skillfully guided the discussion to a powerful conclusion in which children were asked to use their developing explanation for melting to predict the results of a subsequent investigation – what happens to the objects when the heat source is removed.

While elements of argumentation are present in the discussion (e.g., agree/ disagree), we assert that the conversation is a rich context for sense-making in other ways. Ms. Windmere is thoughtfully eliciting students’ ideas and adjusting her next moves responsively. Students are required to use evidence to find patterns, as well as support their claims about melting with evidence. Peers are learning the norms of productive participation in science talks with guidance from the teacher. Taken together, these interactions reflect epistemic practices that support sense-making.

SENSOCIENCIA PROJECT: SCIENCE WITH SENSE AND SENSATIONS

María Martínez-Chico, M. Rut Jiménez Liso, and Rafael López-Gay

SensoCiencia is a Spanish project framed within the current recommendations of integrating understanding the ideas of science with engagement in scientific practices, as they build citizens' proficiency and appreciation for science, imply a richer and more complex reasoning, give an opportunity to reflect on the status of their own knowledge and their understanding of how science works, and can be more inclusive and motivating by embracing an instruction encompassing gender, culture, and emotions aspects.

Generally, these practices are not widely implemented in science classrooms, and, if they exist, are limited to hands-on activities but forgetting minds-on activities. Accordingly, the aim of SensoCiencia Project is promoting scientific practices by focusing on the design, implementation, and evaluation of micro-sequences of activities "Sens-pills" (1.5 hours) that are implemented in different contexts:

- in (Primary and Secondary School) pre-service teacher training programs to promote hands-on and minds-on activities in their future teaching. Learning and emotional self-reflection are incorporated in the sequences, letting pre-service teacher to perceive and self-regulate their learning and emotions, making them aware of what they feel when they are experiencing this approach.

- in (Primary and Secondary School) in-service teachers' classrooms, with their own students, to give them the opportunity of recognizing the effect of scientific practices on students learning, engagement and emotions.

Different instruments have been designed to test the Sens-pills efficiency. Preliminary results show pre-service teachers learn scientific contents from real contexts that make sense to them, and reflect on the emotions and experienced learning. Furthermore, in-service teachers aware of scientific practices effectiveness regarding learning scientific contents (key ideas and epistemic knowledge) and their students' engagement and motivation, so it's reasonable to assume that Sens-Pills implementation can work as "evidence" of the advantages of developing scientific practices in their classrooms. This has relevance, when considering that being aware of the real advantages of teaching approaches, is essential for teachers to decide to incorporate them into their teaching practice.

ENGAGE: EQUIPPING THE NEXT GENERATION FOR ACTIVE ENGAGEMENT IN SCIENCE

Maria Evagorou and ENGAGE team

ENGAGE is an EU funded project aiming to engage students and teachers in science, with an emphasis on developing scientific practices and responsible citizenship. This is a three stages project, with the following goals: (a) to engage in-service teachers in various scientific practices (argumentation, modelling, asking questions) with an emphasis on the development of responsible citizenship, (b) to engage students in scientific practices, socio-scientific issues and responsible citizenship through their teachers, and (b) to bring teachers and scientists together to help them develop and deliver lessons that reflect the scientific practices in action, and discuss issues of responsibility. In order to engage students with science, the driving question behind all lessons was linked to news and to students' everyday lives. The materials developed for teacher professional development, and all the lesson plans are available on www.engagingscience.eu. One of the main research goals is to explore how in-service teachers develop or changing their teaching practices to include scientific practices and responsible citizenship as part of their teaching.



STEAM4U: RAISING STUDENTS' PERCEIVED SELF-EFFICACY IN STEAM TO PROVIDE OPPORTUNITIES FOR ALL

Digna Couso and STEM4U team

STEAM4U is an EU funded project that aims to increase the perception of self-efficacy in the STEM field of children and youth of under-represented groups, with a clear gender and equity orientation. As such, STEM4U develops tools for measuring self-efficacy and other variables related with the “STEM stance” of children age 10-14, in addition to artefacts to help students have success in STEM, to promote a more positive and empowered perception of themselves regarding the STEM field. Some actions of STEM4U include the change of traditional curriculum both in Science and Maths to embrace the “scientific practices” perspective, by involving kids in meaningful participation in scientific inquiry and mathematical reasoning.



SCIENCE 20/20. BRINGING ELS INTO FOCUS THROUGH COMMUNITY – SCHOOL – UNIVERSITY PARTNERSHIP

Carla Zembal Saul and SCIENCE 20/20 team

Given the rapidly changing demographics in the United States, Zembal-Saul and her colleagues proposed an ambitious, design-based professional development model for implementation in a nascent immigrant destination in the northeastern part of the country. Based on census data from 2000 to 2013, the Latina/o population in the focus community increased from 5% to 40%. Many families, particularly from the Dominican Republic, have moved into the area given an abundance of low wage positions resulting from packaging and distribution centers in the region. Almost ¼ of the students in the district are designated English Learners (ELs), and most of the school-aged children speak Spanish as their first language. The cornerstone of the project is dual capacity building among parent ambassadors and a core group of educators.

The Science 20/20 conceptual framework is based on three major tenets. First, Knowledge Building in science and English language development (ELD) exhibit inherent tensions that the project aims to address. Another hallmark of Science 20/20 is a focus on Productive Participation in sensemaking. Finally, Informal Formative Assessment serves as the third key feature of the Science 20/20 conceptual framework.

The research associated with Science 20/20 investigates how the project strengthen participants' capacities to translate language and content knowledge into changes in teaching practice, how the project influences the culture of schools and the community, and to what extent the project translates into measurable improvement in English learners' engagement and achievement



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NATURE OF SCIENCE, SOCIAL JUSTICE AND SUSTAINABILITY

NATURE OF SCIENCE, SOCIAL JUSTICE AND SUSTAINABILITY

In the post-truth era, there is increasing mistrust in science and erosion regarding the authority of truth. The planet is facing significant environmental challenges which can be perceived as the vandalising of the planet. Science education has the responsibility to address these challenges by instilling in teachers and students the set of skills that will help improve their lives and their communities. Science education has the purpose of explaining and predicting phenomena but also help the agenda of planetary preservation for sustainability of life. There is an implication for the conceptualisation of nature of science (NOS) to be inclusive of components that would be responsive to these changes. Part of this issue has to do with freeing science teaching and learning from the constraints of the subject matter.

Another issue is adopting and enacting the complexity of the nature of science in science education without burdening teachers and students to the point of irrelevance. There are also tensions between the different goals of science education in terms of qualification, professionalisation, activism that would need to be reconciled. There are implications for how teachers' roles are defined in this landscape and what counts as effective teaching for different goals of science education, including the inclusion of social justice as a component of science education. There are implications, then, for the content of teacher education. As such, there is a system to be influenced at the level of the classroom, the school, the education system.



KEY CHALLENGES FOR EACH THEME

Some of the key challenges related to nature of science, social justice and sustainability issues in relation to science education can be framed with a set of questions:

1 *How can the complex nature of science be taught and learned in a meaningful and effective way?*

- How can NOS be taught and learned in an inclusive way?
- How do we ensure complex understanding of nature of science without burdening teachers and learners?
- How do you change school science to implement NOS effectively?
- How can subject matter knowledge of science be redefined with NOS as integrated part of it?
- How do you teach multiple understandings of NOS?
- In school science, NOS is generally taught in a way that is not holistic. There is more emphasis on scientific knowledge and scientific practices. On the other hand, there is limited focus on social and institutional aspects of science and relationships among cognitive, epistemic and social-institutional aspects of science. However, to make the nature of science meaningful for students we should teach all these aspects in an explicit and holistic way. Thus, we can ensure students to what science is about, how scientists do science, and the aspects which affect the way scientists do science.
- How can we engage teachers in an understanding of the nature of science as a necessary topic to teach and learn?
- How can we give teachers/schools a voice in setting regional agendas for teaching and learning, in and out of school?
- How can we link science learning to students (and teacher) current experiences of life to ensure meaningful learning?
- How do we teach science to students at all educational levels (a developmental approach to teaching NOS)?
- How can teaching and learning NOS foster/contribute to social justice?
- How can we rethink what science is, and the role of uncertainty, complexity and unpredictability?
- What is the role of teacher education and professional development of teachers?

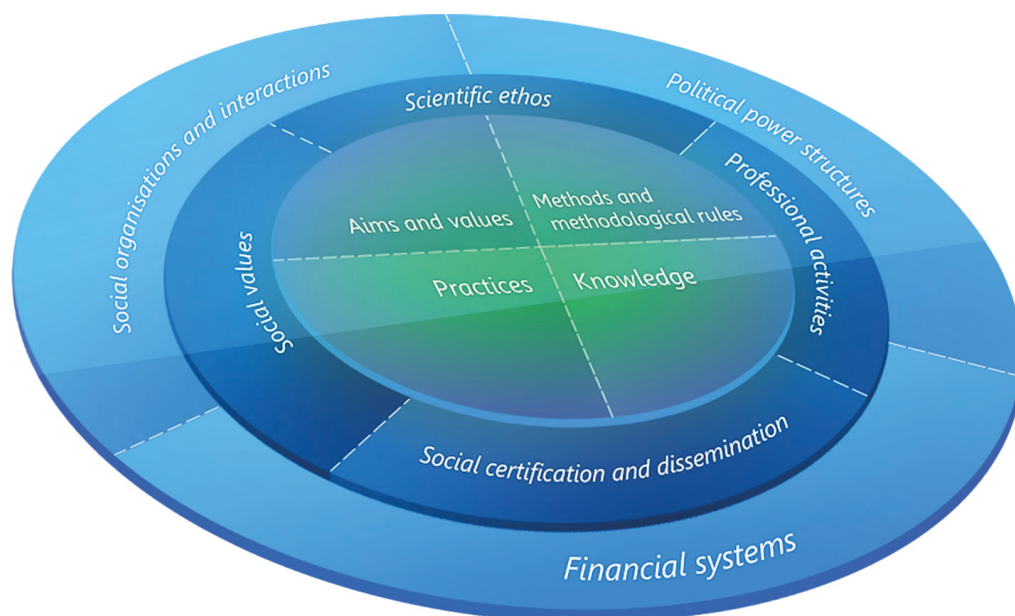
2 *How do we reconcile activist and disciplinary/academic accounts of science?*

- Is science as conserving/subverting or transforming activity?
- Who is setting the agenda (national governing bodies, state boards, parents, teachers and/or other local stakeholders)?
- Who is defining science? And are these defining entities changing?
- Who should define science and therefore contribute to the discussion about the necessity of teaching NOS?
- Does developing a curriculum involve a democratic process or a cooperative/collaborative process? That is how do we determine what to include or exclude from a curriculum?
- Science in national curricula - providing the basics for further study, imperatives of labor market. Also literacy, but most often in the narrow sense of practical literacy. OECD/PISA has provided some impetus to put more emphasis on societal issues.
- Traditionally science derived its authority from providing a coherent and resilient body of knowledge. This is what turns some people off about science, but is also composes the identity of those who are in (including most teachers in secondary and higher ed.). Moreover, we would do our pupils a disservice if we withhold them access to this powerful body of knowledge (e.g. Young, 2013). Yet, the relevance of science knowledge to solving the urgent problems of our time is not self-evident, and no single discipline can claim to solve these problems, so there seems to be a need for a more transdisciplinary take on science education (Venville et al.).
- Teachers views on science influence their willingness to adopt issues-based approaches (cf., Roberts, curriculum emphases), and an activist take on science education may lead to tensions with both their science identity and their teacher identity. If teachers are willing to adopt issues-based and activist approaches, they will face many concerns and hurdles :
 - Uncertainty about open ended approaches
 - Uncertainty about required content knowledge (interdisciplinary)
 - Lack of teaching repertoire
 - Pressure to cover curriculum
 - Lack of collegial collaboration
 - Lack of facilities/opportunities (e.g. leaving the school grounds)
- How can social justice be linked to nature of science?
- How can multiple justices (e.g. environmental, species, planetary justice) be linked to NOS?
- A different way of defining science, and of teaching science, might also require reflection on the way of doing research itself
- Teach less science to insure that we have the time to teach NOS?
- Change assessment approaches to insure that they are aligned with the new views about teaching science.
- Gradually introduce activist/transformational accounts of science while ensuring that the activities and lessons being used have the potential to help students essential science concepts (rigorous curriculum). That is gradually reduce the “hegemony of content” while using a rigorous science curriculum.
- Promoting or integrating citizenship education and global citizenship competences in science education.

CONCEPTUALIZATION OF KEY CONSTRUCTS

Nature of science

Nature of science has been defined from a range of perspectives. One perspective relates to a definition that considers science as a “cognitive-epistemic and social-institutional system” (Erduran & Dagher, 2014). Given the holistic and inclusive orientation of this perspective of the various dimensions of the nature of science (e.g. scientific aims and values, practices, political and economic underpinnings), it is likely to embrace the diversity of challenges that science education faces. The following figure proposed by Erduran and Dagher captures NOS in an inclusive and holistic fashion:



The figure is called the “FRA wheel” and it presents science as an epistemic, cognitive and social-institutional system. It is from Erduran and Dagher’s (2014) book (p.28).

Erduran, S., & Dagher, Z. (2014). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories*. Dordrecht: Springer.

Sustainability

Society faces a number of 'wicked' problems such as biodiversity loss, climate change, poverty and failing education systems. Wicked problems have been conceptualised as 'complex, contested and ambiguous with respect to their underlying values and causes' (Sol Ir et al., 2017). All of these issues relate to the relative sustainability of economic and environmental systems. Activist scholars such as Rotmans argue that transition perspectives are essential for engaging with these problems (Rotmans and Loorbach 2006). In education, such an approach might mean shifting 'from individual learning, personal development and competition to joint learning, community building and solidarity' (ibid.). Progress would be indicated by an evolution 'from a stage of self-perpetuating and self-replicating unsustainability towards one that is more sustainable' (ibid.).



FORWARD-LOOKING VISION

Theoretical recommendations

- Synthesis of theoretical frameworks that are inclusive of nature of science, social justice and sustainability
- Conceptualisation of teaching to be inclusive of the ability to infuse complexity in learning environments

Methodological recommendations

- How to assess issue-based, action-based curricula?
- Trans/inter-disciplinary approaches to social justice/science education interphase

Practical recommendations

- Systems to be impacted (levels of teaching-learning, schooling, district/region, country)
- Distinguish key stakeholders to bring about changes in the educational system, and reconsider how 'education research' communities relate to them
- Explore the close relation between science communication research and science education research, and how they underpin engagement programmes of science and engineering itself (RRI inspired or other)
- Define possible strategic pilot studies as showcases
- Capacity building for the above
- Invest in continuity and sustainability of practical recommendations
- Monitor change processes

EXAMPLES OF CURRENT PROJECTS

PROMOTING CITIZENSHIP COMPETENCIES IN SCIENCE EDUCATION WITH AUTHENTIC AND INNOVATIVE TEACHING MATERIALS

Bayram-Jacobs et al., The Netherlands

In the natural sciences exam programs in the Netherlands, 'informed decision making' is included as an important aspect of critical-democratic citizenship. There are a few teaching materials for citizenship education in Dutch language for these subjects, and the societal subjects in these materials are getting outdated quickly. Teachers need guidelines and tools to be able to design lessons in which pupils learn to give a substantiated opinion about current social issues, such as: 'vaccines for 'unhealthy' lifestyles: yes / no?'. A consortium of three school groups and three universities (7 people) forms a professional learning community (PLC) during this short-term educational research. In this PLC proven design principles are derived for education on informed decision making in the science subjects and by using 5E learning cycle the consortium develop curriculum materials. In this way, we want to contribute to promoting effective citizenship education in these subjects and providing guidelines for teachers.

SCIENCE TEACHER EDUCATION ON NATURE OF SCIENCE

Kaya et al., Turkey

The project aimed to (a) develop lesson materials to teach an inclusive and holistic account of nature of science in school science, and (b) improve pre-service science teachers' understanding and perceptions of nature of science. A total of 15 female senior year pre-service science teachers participated in a series of 14-week workshops. A variety of teaching strategies which included group discussions, presentations and projects were used. The data sources were pre- and post-questionnaires including 70 items, pre- and post-interviews with individual pre-service teachers, pre- and post-representations, and resources such as posters and lesson plans. Quantitative and qualitative data analysis results suggest that the teacher education intervention facilitated pre-service science teachers in relating different aspects of nature of science. The project has implications for research and development on nature of science including the nature of methodological approaches and analytical tools for studying teachers' perceptions and understanding of nature of science.

INTERDISCIPLINARY CONNECTIONS IN SECONDARY SCIENCE TEACHER EDUCATION

Savelsbergh et al., NL

In the Netherlands, secondary teacher education runs very much along disciplinary lines: we have biology teachers, chemistry teachers, physics teachers, geography teachers and technology teachers. The separation has been reinforced by the introduction of nation wide “knowledge standards” a few years ago. Within this context we are working in a PLC with teacher educators in our university to create an issues-based interdisciplinary course where teacher students from all the above domains will get acquainted with each other’s domains, and collaborate to teach an issues-based module in secondary education. Evaluation focuses both on the concerns of the educators, the design of the module, and the learning experiences of the students.

INCLUSIVE SCIENCE TEACHING IN MULTILINGUAL CLASSROOMS - A DESIGN STUDY

Hajer, Savelsbergh, Jacobson, Kvammen, 2018-2021

Norway, Sweden and the Netherlands face similar challenges in providing high quality science teaching for all, given the high influx of newly arrived students, but there are remarkable differences in approaches towards hyper diversity in mainstream classes. Dutch educational authorities offer general frameworks but do not interfere with teachers pedagogical choices nor in professional development, in contrast to a very active Swedish National Agency. The project aims to contribute to inclusive science education through studying teachers classroom work across educational contexts, when provided with innovative tools to explore new literacy approaches and integrate them in their planning of inclusive lessons. Acknowledging the importance of science literacy to multilingual students achievements in the core subject of science, successful approaches for heterogeneous groups have been identified, in specific 'using multilingual resources', 'using language scaffolding' and 'creating interactive discourse practices'. Teachers will be provided with professional development and Inclusive Science Materials and their enactment will be studied. Main research question is 'What literacy oriented approaches can be successful for

inclusive science education in multilingual primary classrooms in different educational contexts' ? Three parallel case studies, one for each country, will be conducted in heterogeneous classrooms, in which children with migrant background (newly arrived or not) or a multi- and/or minority language background learn together with mother tongue speakers of the language of instruction. Teachers are the key persons to adapt pedagogical approaches therefore close cooperation between researchers and teachers is required. For this reason, Educational Design Research provides a suitable approach. In each country, we will conduct a design study. Teachers will use the same inclusive science thematic packages and we will follow how and why they use these the way they do. We record teachers conversations in which they adapt thematic units, developed by the researchers to their own practice. We introduce the units in professional development sessions. Of course, also student outcomes and actual participation in classroom activities will be monitored. Apart from theoretical outcomes, practical materials will be available for teacher training.

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INSTEAD OF A CONCLUSION

The world is changing, so science education much change too. While globalization opens up new opportunities for learning, societies face rising and complex challenges, which call for new perspectives on the kind of education we need for the future. The theoretical assumption that this workshop was framed within is that a democratic future depends on whether all people are offered exciting opportunities to engage with science and become active consumers of scientific information in a changing world.

The participants of this workshop worked together to share knowledge and experiences and offer recommendations for policy, practice, and research around three interconnected themes of research: *diversity and equity, scientific practices, and nature*

of science, social justice and sustainability. As evident in this report, several challenges and key ideas cut across these themes, inform each other in various ways, and have implications for policy, research, and practice.

The report, though by no means exhaustive, offers an overview of the main current challenges identified and provides a set of recommendations for addressing these challenges as put forward by the participants of the workshop. At the same time, the report provides examples of current international projects that aim to address specific challenges. As such, it offers a starting point for rethinking the fundamentals of science education at a time when the world is changing profoundly.

